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RELATIONSHIP OF VENOUS PRESSURE TO INTRAPULMONIC PRESSURE

A Comparison of Continuous Positive-Pressure Breathing by Mask and by Helmet

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SCHOOL OF AEROSPACE MEDICINE
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BROOKS AIR FORCE BASE, TEXAS

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September 1961

77SR-59577

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Modern aircraft fly at altitudes where man cannot exist without respiratory aid. Failure of pressurization of an aircraft above 50,000 feet will lead to loss of useful consciousness of the occupants in less than 15 seconds (8). Breathing 100 percent oxygen will prolong useful consciousness at this altitude only if it is breathed under pressure.

Pressure breathing is a useful emergency measure to allow descent in case of cabin decompression at very high altitude, and it is still used to increase altitude capability in unpressurized aircraft.

The desired effect of pressure breathing is to increase the arterial oxygen tension. This is accomplished by increasing the oxygen tension in the lungs. As this desired effect occurs, the increase in lung tension has a deleterious effect on the circulation (1, 3, 4, 5). This effect is first manifested by an increase in intrathoracic venous pressure (7), which adversely affects the venous return to the heart (2).

Pressure breathing is commonly accomplished by mask or by helmet. Both of these methods cause an increase in intrathoracic venous pressure, but the effects on venous return from the head to the heart should be different by the two methods.

This study will compare the venous-pressure changes caused by continuous positive-pressure breathing by mask and by helmet as an approach toward determining which method of pressure breathing may be more favorable for venous return from the head to the heart.

Received for publication on 12 June 1961.

METHODS

Dogs were used in these studies because it was not feasible to make these direct venous measurements on human subjects. To study continuous positive-pressure breathing and to change rapidly from mask breathing to helmet breathing, a special respirator was built (fig. 1).

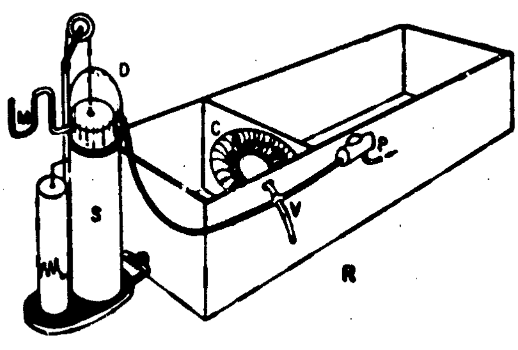

FIGURE 1

Experimental set up: R, respirator; P, pressure-vacuum pump; V, valve; C, respirator collar; S, spirometer; D, dome; and M, manometer.

This respirator had a large chamber for the dog's body and a smaller chamber for the dog's head. The two chambers were separated by a partition which contained an adjustable respirator collar. The two chambers had separate covers so that they could each be left open or sealed airtight. Each cover had a clear leucite panel so that the dog could be observed inside the respirator.

A motor-driven, pressure-vacuum pump was mounted on the side of the respirator. This pump could supply positive pressure to the head chamber or to the spirometer from which the dog breathed, or to both simultaneously. Thus, the lungs and head could be pressurized to simulate helmet breathing, or the lungs alone could be pressurized to simulate mask breathing. In either case, the body chamber was left at ambient pressure. Negative pressure could be created in the body compartment to produce positive-pressure breathing by still another method, although this method was not used in this study.

The experimental animal was at all times connected to the spirometer via a tracheal cannula. When the pump was not pressurizing the spirometer, the dog was breathing at ambient pressure; when the spirometer alone was pressurized, the dog was pressure-breathing by "mask"; when positive pressure was applied to the spirometer and head chamber simultaneously, the dog was pressure-breathing by "helmet." By simply changing the position of a three-way valve on the output side of the pump, normal breathing, pressure breathing by "mask," and pressure breathing by "helmet" could be studied in quick succession.

Pulmonary volumes were recorded from a 13-liter, oxygen-filled spirometer with a CO_2 absorber. This spirometer had been modified to permit its use for pressure breathing. A dome had been fitted over the spirometer bell and secured to the outer wall of the water compartment so that the bell moved freely within the dome. When the dome was pressurized, the pressure was transmitted to the spirometer bell and through the connecting tubes through the wall of the head chamber into the tracheal cannula and into the lungs of the dog.

Six mongrel dogs were studied. Before being placed in the respirator, they were prepared in the following manner: They were anesthetized with intravenous sodium pentobarbital. A tracheotomy was then performed and a tight-fitting cannula was tied into the trachea. The right jugular vein was exposed in the neck, and two catheters were inserted. One catheter was directed downward so that its tip was intrathoracic and in the superior vena cava just above the heart; its position was verified at autopsy. The other catheter was directed cephalad so that it recorded extrathoracic (jugular) venous pressure in the head. Both of the catheters were inserted through needle punctures of the vein wall and did not occlude the lumen of the vein. An esophageal balloon was placed in the esophagus to record intrapleural pressure (1).

The dog was then placed in the respirator, and the tracheal cannula was connected to the spirometer. Differential strain gages were connected between (a) the esophagus and ambient pressure, (b) the trachea and ambient pressure, (c) the trachea and esophagus, (d) the superior vena cava and ambient pressure, and (e) the right jugular vein and ambient pressure. Continuous records were thus obtained of intrathoracic pressure, pulmonic pressure, transpulmonary pressure, superior vena cava pressure, and right jugular vein pressure. A continuous spirogram was recorded by the spirometer

Records were made with the dog breathing at ambient pressure and at +10, +20, +30, and +40 cm. H_2O pulmonic pressure applied by "mask" and "helmet." The pressures were applied in succession and maintained at each level for approximately two minutes. All measurements were obtained, as indicated by the method, with the animals in the supine position.

FINDINGS

Mask pressure breathing

With increasing pulmonic pressure, the superior vena cava pressure rose from an average of 1 cm. H_2O at ambient pressure to an average of +23 cm. H_2O when 40 cm. H_2O of intrapulmonic pressure was applied (fig. 2). At the same time, the jugular venous pressure rose from an average of +11 cm. H_2O at ambient pressure to +23 cm. H_2O when +40 cm. H_2O of intrapulmonic pressure was applied. The difference between jugular venous pressure and superior vena cava pressure varied from +12 cm. H_2O at ambient pressure to 0 cm. H_2O when +40 cm. H_2O of intrapulmonic pressure was applied, indicating that at these high pressures blood flow from head to heart virtually ceases.

Helmet pressure breathing

With increasing intrapulmonic pressure, the superior vena cava pressure rose from an average of 1 cm. H_2O at ambient pressure to an average of +23 cm. H_2O when 40 cm. H_2O of intrapulmonic pressure was applied (fig. 3). At the same time, the jugular venous pressure rose from an average of 11 cm. H_2O at ambient pressure to 42 cm. H_2O when +40 cm. H_2O of intrapulmonic pressure was applied. The difference between jugular venous pressure and superior vena cava pressure varied from +12 cm. H_2O at ambient pressure to +18 cm. H_2O when +40 cm. H_2O of intrapulmonic pressure was applied. In this case, contrary to the "mask" situation, pressure gradients for blood flow from head to heart are even more favorable than normal.

For mask pressure breathing, the differential venous pressure from head to chest (fig. 4) varied from +12 cm. H_2O at ambient pressure to 0 cm. H_2O at +40 cm. H_2O intrapulmonic pressure. For helmet pressure breathing, the differential venous pressure from head to chest varied from +12 cm. H_2O at ambient pressure to +18 cm. H_2O at +40 cm. H_2O of intrapulmonic pressure.

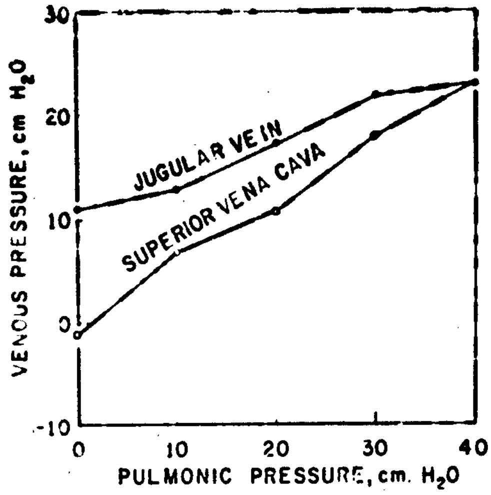

FIGURE 2

Relation of venous pressure to intrapulmonic pressure: continuous positive-pressure breathing by mask.

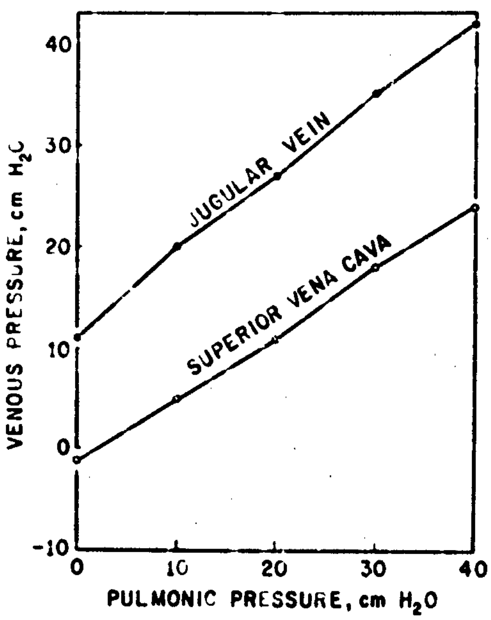

FIGURE 3

Relation of venous pressure to intrapulmonic pressure: continuous positive-pressure breathing by helmet.

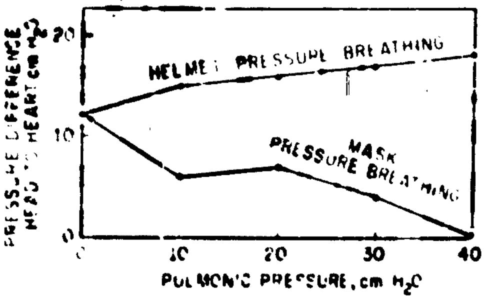

FIGURE 4

Differential pressure between jugular vein and superior vena cava; comparison of effects of increased intrapulmonic pressure when applied by mask and by helmet.

DISCUSSION

The venous return from the head to the heart is influenced by the pressure gradient between the veins of the head and the veins in the chest (7). Normally, the venous pressure in the chest is slightly below ambient pressure while the venous pressure in the neck and head, particularly in the supine position, is slightly above ambient pressure. This normal pressure gradient facilitates the return of venous blood to the heart.

When intrapulmonic pressure is increased, a considerable amount of this pressure is transmitted to the great veins in the chest and thus the pressure in these veins is also increased. Since these veins are collapsible structures, the pressure in them must always be slightly greater than intrathoracic pressure if blood is to return to the heart. In order for venous blood to return from the head to the chest, the pressure of the venous blood in the head must be increased above that of the veins in the chest.

When increased intrapulmonic pressure is applied by mask, venous pressure in the chest is increased as discussed above. This increased venous pressure is transmitted backward to the veins in the neck and head. Since many of the veins on the periphery of the neck and head are embedded in relatively loose surrounding tissues and since veins are distensible structures, the increased back pressure from the veins in the chest causes these neck and head veins to distend. Thus, with mask pressure there is venous distension in the neck and head. With this venous distention there is increase in venous volume in the neck and head and relatively less rise in venous pressure as compared to the rise in venous pressure in the chest.

When increased intrapulmonic pressure is applied by helmet, venous pressure in the chest is again increased as discussed above; however, since the head and neck are enclosed in the helmet, the increased pressure applied by the helmet is directly applied to the head and neck as well as to the respiratory tract and lungs. Thus, although venous pressure in the chest is increased, the venous pressure in the head and neck is increased by at least an equal amount because the head and neck are enclosed in the helmet.

It has been shown that with increased intrapulmonic pressure applied by mask, the pressure in the superior vena cava rose with the increase in intrapulmonic pressure. The pressure in the jugular vein did not rise sharply during this period and at +40 cm. intrapulmonic pressure, the jugular pressure and superior vena cava pressure were essentially equal. This increase in superior vena cava pressure, accompanied by a lesser rise in jugular vein pressure, created a pressure gradient that became increasingly adverse for venous return from the head to the chest as intrapulmonic pressure was increased.

With increased intrapulmonic pressure applied by helmet, the venous pressure relationship between the head and the chest was different from that seen with mask breathing. With increase in intrapulmonic pressure, the pressure in the superior vena cava again rose; however, the jugular vein pressure also rose directly with increased intrapulmonic pressure, and at any point in the increase of intrapulmonic pressure, the jugular venous pressure rose by an amount greater than the corresponding rise in superior vena cava pressure. This pressure gradient was favorable for the return of venous blood from the head to the chest.

SUMMARY

During continuous positive-pressure breathing by mask, the superior vena cava pressure rose relatively more than did the jugular venous pressure; thus a relatively unfavorable venous pressure gradient was established for the return of blood from the head to the heart.

During continuous positive-pressure breathing by helmet, the jugular venous pressure rose relatively more than did the superior vena cava pressure; thus a favorable venous pressure gradient was established for the return of blood from the head to the heart.

From the standpoint of pressure gradients, venous return from the head to the heart was more favorable when pressure-breathing by helmet than when pressure-breathing by mask.

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